Spatial Data Analysis in Archaeology : A comparison of two available methods for site location

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Spatial Data Analysis in Archaeology: A comparison of two available methods for site location

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Abstract—This contribution validates the integration of multicriteria (MC) optimization and Agent-Based Modelling (ABM) as complementary methods for the planning of survey and fieldwork. In our case study, multicriteria approach and ABM are presented as the most efficient methodological framework to analyze settlements distribution in sedentary societies.

Keywords—multicriteria, agent based modeling, site location, predictive modelling

1. Introduction

The main aim of this contribution is to present and argue for the integration of diverse methods of spatial data analysis used for the identification of possible locations of archaeological sites. We investigate the possible application of multicriteria (MC) optimization and Agent-Based Modelling (ABM) as complementary methods for the planning of survey and fieldwork. There are significant methodological differences between these two approaches, starting from the types of data (i.e., autonomous vs non-autonomous agents) these methods are best suited to work with, to their final outputs they produce. Their aim though is quite similar as they focus on determining the most efficient methodological framework to plan and conduct a successful field archaeological research with limited waste of resources and time.

In our paper we discuss a theoretical multicriteria approach and ABM combined framework, to analyse sedentary societies with an agriculture-based economy and characterised by long-lasting settlement patterns. Although these methods could also be employed in the analysis of semi-nomadic and nomadic societies, due to our dataset we apply this method initially to sedentary groups, which are influenced by social and environmental changes (e.g. change of central government, climate changes that include both seasonal regular changes and irregular alterations that affect the progressive diminishing resources).

The main purpose of integrating these methods is to support archaeologists in the analysis of distribution and location of potential sites and hence creating a more efficient and goal-oriented surveying strategy. Similar methods of spatial analysis in archaeology have been investigated elsewhere (see Arıkan, Balossi Restelli, Masi 2016; Siart et al 2008; Evans et al 2011; Rihll, Wilson 1987).

2. Multicriteria Method (MC)

The multicriteria approach is based on the notion of optimization with respect to various criteria, such as distance from water sources or the topography of the area. Within this method, it is not necessary to find the optimal solution, as we are looking for the set of sigma optimal values that fulfil the requirements, in which the sigma value represents the deviation of the local value for a given criterion from the optimal value, and therefore these highlight possible locations of archaeological sites. Optimal value is a theoretical, "ideal" point where all values are "best". Minimum in terms of e.g. distances and maximum in terms of e.g. possible natural source size/capacity. This is a reference point for the analysis. Local value is the value for a given cell of the outcome of all the given criteria, e.g. distance from water sources, the slope of the terrain.

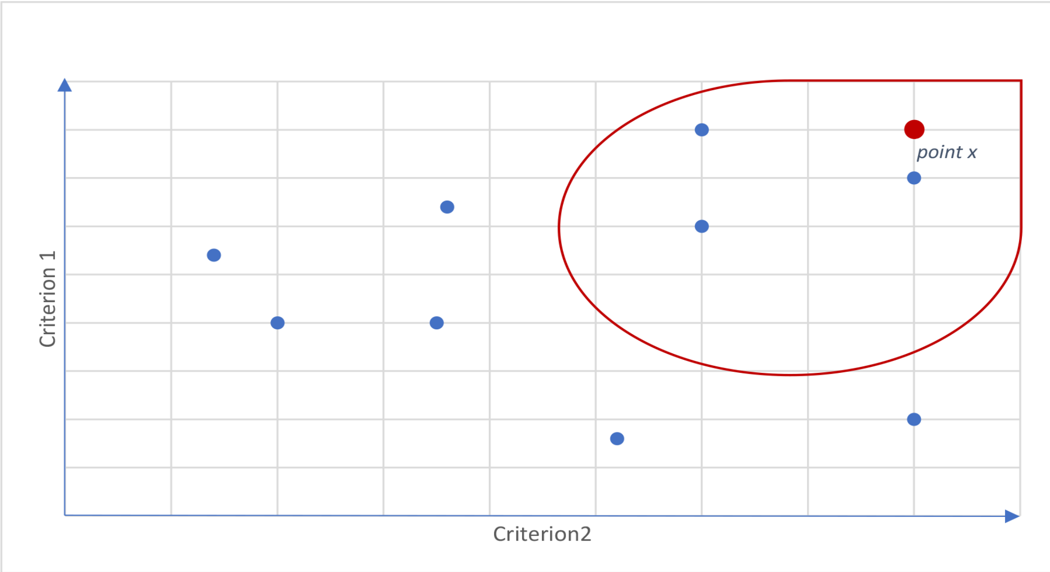

Fig.1. Point x denotes the optimal value for both criteria; red denotes the extent of the sigma values not exceeding the predefined requirements (where sigma is between 0 and the predefined value, i.e. 2 km). The axes represent the values for of the criteria.

The outcome of such a method is a set of locations that fulfil a predefined set of requirements, for example: 1) areas that are located no further than 2 km from water sources, 2) no further than 2 km from arable land, **and** 3) on the slope less than 5 degrees. These requirements can be adjusted, based on the specifics of the investigated landscape or culture analysed. Next, the selected locations from this initial set are classified according to the weighted sum of the sigma values with respect to each criterion. The higher the sigma the further is the given location from a predicted optimal point (cell). The weights are assigned based on the experts' knowledge and on the analysis of the results of the experiment carried out on the training set.

Fig.2. Each circle denotes one of the proposed criteria. Each represents a set of sigma optimal values. The cells we are looking for are in the area where all three sets overlap.

For the multicriteria-based method the following methodology was adopted:

1. The investigated area is divided into a regular grid forming squares/cells, any subsequent computation is done with reference to the centre of each cell.

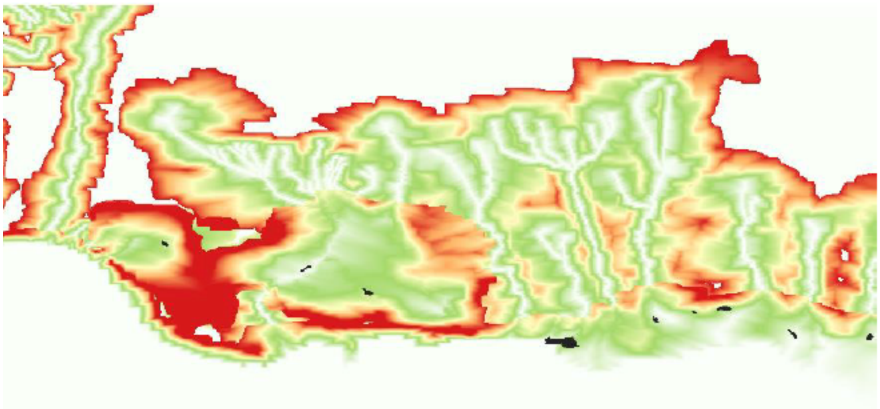

Fig. 3. An example of the result of the application of the MC method. The areas with the lowest sigma values (highest probability of a site being located there) are marked in green, the highest sigma values are marked in red. The white areas have been completely eliminated from the analysis (mountain peaks, sea).

2. We eliminate the extreme points (that is points that do not fulfil the requirements) from the map of the investigated area. In this step, we also eliminate locations where a site could not be located, e.g., on sea, or a steep mountain slope.
3. For the data prepared in the previous steps, we define a function of "difficulty of the terrain", which determines the cost of travel from one point to the other: It's the standard deviation of height above sea level in given cell i.e.

$$s(x_i) = \sum_k |p_i^k - x'_i|$$

where:

x_i represents given cell,
k is a number of pixels in a cell,
x'_i is a mean value in given cell,
p_i^k is a height above sea level for given pixel in cell represented by point x_i.

4. We calculate the optimal sigma values for each criterion separately, including the required limitations (e.g. no more than 2 km from the water source), these values include the calculated travel cost value. The travel cost is a criterion limiting the distance to a resource. We have assumed that the maximum walking distance of 5km in certain cases must be reduced and include the cost of crossing a natural barrier, e.g., in a mountainous terrain it can be reduced to even 1 km. The difficulty function may be also used in step 2. We can eliminate some extreme points taking into account different locations from different maps with similar conditions.

5. A weighted sum is calculated, taking into account all criteria i.e. $f(x_i) = \sum_{j=i}^{d} w_j f_j(x_i)$, where d represents the number of different criteria.
   Weights may be given by the decision maker (archaeologist), or by series of experiments based on known locations from an archaeological survey in areas with similar environmental conditions and coming from the same culture and time period. The values of function $f(x_i)$ classify points x_i on the map.

This method has been tested by the authors elsewhere (Bienkowski, Leśniewski and Radziszewska 2018), for a dataset for the medieval period in South Crete. It was first tested against a set of known locations and gave promising results.

3. Agent Based-Modelling (ABM) Method

The Agent-Based Modelling approach is based on the idea of modelling interactions between autonomous agents such as natural resources available (e.g., land available), environmental data (e.g., climate), anthropological

factors (e.g., type of society, type of leadership and taxes), population estimate, and external factors (e.g., conflict) that follow diverse behavioural patterns in order to analyse possible developments of complex society over time (Arikan, Balossi Restelli and Masi 2016; Crabtree and Kohler 2012).
The goal of the planned model is to study the outcome of interactions between the agents used in the MC in order to compare results and in a second phase to weight it up with the data collected in the field, thus determine a likely reconstruction of societies socio-cultural transformations and their impact on the material remains. Within this approach, it is possible to model interactions, not only between people and the environment but also between the agents themselves (e.g. trade, cultural contacts, interactions between segments of society such as elites and the non-elite portion of society). We are planning to run the ABM in the NetLogo environment, which is both open access and allow for greater flexibility in setting up the parameters for the modelling (Fig.4).

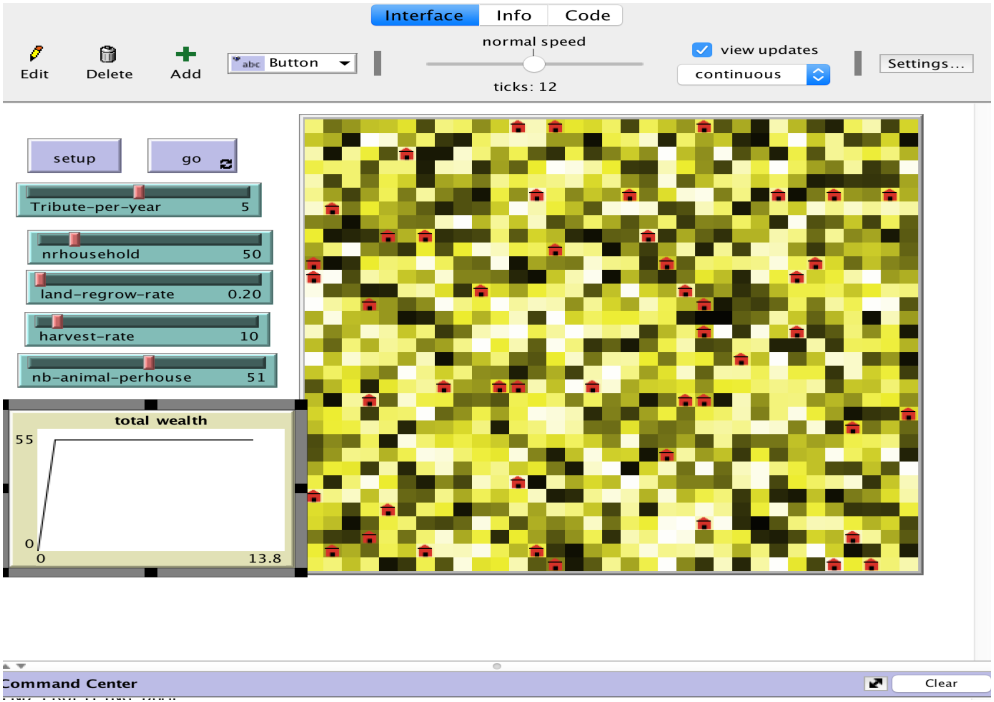

Fig. 4. Example of a prototype ABM to be further developed alongside the MC.

The ABM has been theorized as integrated to a GIS map of the area in order to present detailed historical conditions (e.g. digital elevation model, water sources, arable land). In particular, we are planning to include GIS files with the pertinent data in the NetLogo environment as a base for the model creation. As shapefile and raster images can be easily integrated and manipulate during modelling to answer the different experiments set up (Cegielski and Rogers 2016).

In the case study theorized so far, ABM has been set up with the same variables of the MC (Fig.5), to detect settlement pattern aimed at gaining access to natural resources in a changing environment (e.g. both seasonal and climate changes exemplified by pluviometry variability, access to natural resources, high variability of household resources based on central government demands). The model tries to factor agents, which are both collaborating and/or competing with other groups (e.g., sedentary society) and within the framework established by the central government.

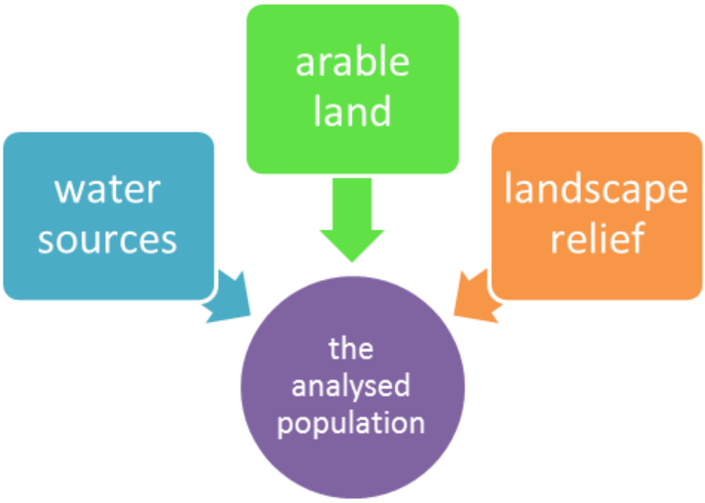

Fig. 5 A scheme of the ABM method. The choices of a population concerning different criteria are investigated in order to uncover new sites.

All these variables provide motivation to the agents to interact and exhibit distinct patterns of behaviour, creating a model variability that can then be tested against empirical archaeological data during the survey. Furthermore, ABM allows to experiment on additional variability patterns in laboratory settings, thus allowing archaeologists to test multiple theories on societies occupational development over time within a flexible, multi-factors environment (Altaweel 2006; Dean et al. 2000; Doran 2999; Gilbert 2008). Once this ABM has been successfully run through multiple experimental scenarios, future steps will include testing the model against archaeological data collected from the survey.

4. Integration of the methods

While both aforementioned methods aim at assisting researchers in selecting possible site location and conducting an efficient and effective survey, they present different outputs which could and should be combined

Their outputs are originated by the experts' knowledge about the investigated society and the ways it exploited the natural resources. Aside from the location of possible sites these methods help uncover the underlying pattern behind the known network of settlements, possible trade-routes and eventual likely conflict areas.

The multicriteria based approach determines possible site location in a more static manner, under the provided criteria and in a given moment in time, whereas ABM based approach works in a more dynamic way, taking into account the relationship between social groups over time, the high frequency of changing dynamics, and the transformation of the surrounding environment. These differences clearly impact the possible use and outputs of those methods in the archaeological practice, furthering our arguments that these should be combined and implemented during the planning of the archaeological survey. The ABM method finds application in both the preliminary preparation for survey investigation as well as during the interpretative part of the analysis. The multicriteria based method is a quick and efficient tool for the selection of priority locations for surveys as well as a way to establish the presence of any unidentified sites within a known settlement pattern.

5. Preliminary conclusions and Future Perspectives

MC ad ABM methods are geared towards the identification of sites as a result of a more or less conscious settlement pattern of the investigated population (spatial, natural or economic factors). Within this analysis, there may be a number of settlements that are omitted, namely the ones established based on non-environmental, often elusive factors. Such sites are often related to tradition or religion (cult places related to myths and legends) or to a very specific aspect of the landscape (e.g., defensible sites).

Always, when investigating the relation of past societies with their environment, the changes of this environment, as well as socio-cultural traditions, must be taken into account. Depending on the period in question, data from

old maps, historical citations or even information from specialists is required to prepare suitable environmental data for the analysis.
Future investigations include the testing of both with the same data here presented in order to compare results and explore further ways of integrating them within the same computational system. we further plan to use both models to investigate different scenarios such as the movement of semi-nomadic population in Iron Age Jordan to test their reliability and applicability.

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